

Chapter XIV

Conclusion 1960–1990

During its first 30 years, the Marshall Space Flight Center was at the center of many of NASA's most important endeavors. Marshall people helped NASA plan explorations of space, develop complex technologies, and contribute to scientific progress. At each step, they encountered uncertainties because NASA, more than any federal Agency, was charting unexplored territory. In following their dreams and in responding to opportunities and directives, Center personnel shaped their future and the future of American space exploration.

Uncertainties faced NASA from the beginning. In the late 1950s, America's political leaders and space managers debated various plans for space policy. They discussed whether space budgets should be large or small, whether the military or a civilian agency should be primary, whether spacecraft should be robotic or piloted, whether exploration should be Earth orbital or interplanetary. While still in the Army Ballistic Missile Agency, future Marshall personnel contributed to the debates by publicizing their visions of new space technology. With Wernher von Braun leading the way, the engineers and scientists devised concepts of big rockets, space stations, scientific spacecraft, orbiting telescopes, lunar rovers, and lunar outposts. Over the next decades the space team in Huntsville oversaw the conversion of many of these visions into space hardware.

The first steps from dreams to reality came after American policy makers made space exploration an arena for peaceful competition during the Cold War. They wanted a space program that could demonstrate American political, organizational, technological, and scientific superiority over the Soviet Union. The Army's missile specialists in Huntsville became a tremendous pool of talent that could help achieve these national goals. While still in the Army, the team was virtually a space agency in miniature; it developed the Jupiter-C launch vehicle and helped develop the spacecraft for Explorer I, the first American

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scientific satellite, and began work on the Saturn family of rockets, a new generation of large launch vehicles intended primarily for civilian payloads. In 1959 the Army agreed to transfer the missile team to the National Aeronautics and Space Administration, the civilian space organization formed the previous year. In 1960 the Marshall Space Flight Center formally became a NASA field Center.

The first decade at Marshall centered on the Apollo lunar program, and the Center successfully overcame several daunting technical, organizational, and political challenges. The political consensus supporting the Apollo mission facilitated NASA's efforts, and Marshall's engineers benefited from expandable budgets, clear technical goals, and a fixed schedule. Within this secure political environment, the Center's engineering laboratories designed, developed, tested, and operated the Saturn launch vehicles, especially the Saturn V rockets that lifted astronauts to the Moon. To cope with the enormous technical demands of Saturn, Marshall built new facilities, hired more experts, and enhanced its capabilities in systems engineering and project management. Their efforts were so successful that the Saturns never experienced a launch failure, and NASA met President Kennedy's end-of-the-decade deadline for Apollo.

Beyond the addition of personnel and capabilities, the Apollo Program helped change the Center's organizational culture and the political economy of the space program. NASA required that Marshall privatize most Saturn work, using the Apollo program to demonstrate the strengths of a public-private partnership and to spread the largesse of space spending across the political landscape. Consequently the Center moved away from the Army Arsenal system, which developed prototypes and some flight hardware in-house, and toward the Air Force system, which relied on contractors. Moreover NASA and the Johnson Administration directed the Center to pioneer new race relations, a directive Marshall carried out well enough to help remove most legal barriers to equal opportunity in Madison County. The tremendous successes of the Apollo Program convinced Center personnel and many Americans that NASA could overcome any challenge.

Even before the lunar landings ended, however, NASA began experiencing uncertainties that helped create a crisis for Marshall. Beginning in the mid-1960s, the Agency planned new missions to follow Apollo, but no new program had the political mandate that had supported NASA's lunar missions. At the same time, the Marshall Center was finishing Saturn development and its

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personnel were ready for new challenges. Faced with declining budgets and work, the Center experienced a long institutional crisis. From the late sixties until the mid-seventies, Marshall laid off hundreds of workers, and NASA Headquarters even discussed closing the Center.

In response to the crisis imposed from outside, and to pursue their perennial dreams of space exploration, Marshall people recognized that they had to find new tasks. Consequently Marshall reorganized to compete with other NASA field Centers for new projects and diversify outside of their propulsion specialty. In 1968 the Center created a Program Development Office which helped technical specialists from the labs devise preliminary plans and designs, and thus win new projects. In 1974, Marshall formed a more flexible laboratory organization to facilitate cooperation of specialists drawn from several different labs and to solve the complex problems of diverse projects.

With this new organization, Marshall branched beyond propulsion and successfully diversified into spacecraft engineering and space science. The most dramatic early achievement of diversification was *Skylab*, America's first space station. The Center oversaw construction of *Skylab* from a Saturn V upper stage, and built many of its subsystems, including the Apollo Telescope Mount (ATM). It also supported *Skylab*'s myriad scientific experiments, from the sophisticated solar studies of the ATM to the simple observations of spider web formation in a student experiment. Before the end of the 1970s, Marshall people oversaw development of the lunar roving vehicle, three high-energy astronomical observatory satellites, a general relativity experiment, a geophysics satellite, and solar energy and coal mining research.

In conceiving and winning new tasks, Marshall ensured its survival and became NASA's most diversified field Center. By the mid-1980s the Center had engineering expertise in launch vehicles and orbital transportation, materials and processes, structures and dynamics, automated systems, data systems, and spacecraft design. Marshall also had scientific expertise in microgravity science, astronomy and astrophysics, solar physics, magnetospheric physics, atomic physics and aeronomy, and earth science and applications.

This expertise resided in the Center's laboratories. While lab scientists and engineers had always supported major projects, such support activities were only a portion of their work. To Associate Director for Science Charles R.

Chappell, the laboratories were the heart of the Center. He compared Marshall's wide-ranging activities to an iceberg, with work on the major projects—Shuttle, Space Station, Spacelab—as the visible tip. Below the surface, spreading wide and deep, were the Center's research and technology programs. The following survey is far from exhaustive, but gives an indication of the Center's vast capabilities.

Just as Wernher von Braun's vision defined Marshall in its early years, in 1990 Marshall's vitality rested on a foundation of imagination. The Center's advanced studies helped NASA conceive future space programs, and generated innovations in research and technology. Space Station work in the 1980s comprised only a portion of the advanced studies conducted at the Center. Marshall also pursued work in transportation systems, space systems, and data systems. Development of new transportation systems to supersede the Shuttle were the most ambitious projects under consideration at Marshall. The Center conducted in-house studies and worked with other NASA Centers, government agencies, and contractors to define the next generation of launch systems and vehicles. Two propulsion projects, the space transportation main engine and the space transportation booster engine, envisioned employing liquid propellants for the next generation of launch vehicles. In related efforts, the Center conducted propulsion studies examining alternative propellants, including varieties of liquids and solids, hydrocarbon, and low-cost auxiliary booster/core systems using liquid-oxygen tank pressurization separate from the engine.

Advanced studies also sought to develop experiments and hardware to further research in space science and applications. Charles Darwin of Marshall's Program Development Directorate described the systems under investigation as "large astronomical observatories that would succeed or complement the Great Observatories, Earth and microgravity science instruments and facilities, geostationary platforms, and a variety of Space Station . . . payloads."¹ These experiments had both theoretical and practical goals. One of the theoretical projects was a spacecraft called Gravity Probe-B, an experiment in gravitational physics designed to test Einstein's theory of relativity by using four precision gyroscopes designed to detect minute changes in the structure of space and time. AXAF, the Advanced X-Ray Astrophysics Facility, was a 43-foot-long, 20,000-pound spacecraft designed to gather data on x-rays over the course of a 15-year lifetime. It included an optical system eight times as precise as that of HEAO-2, an experiment flown in 1978. Several advanced studies projects

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involved the use of tethers, long cables deployed between the Shuttle (or a later vehicle) and a satellite that could be used to carry electrical current, to transfer momentum from the Shuttle to the payload (and thus lift the payload to a higher orbit), or ultimately to help maintain the orbit of a Space Station.²

Advanced systems projects included new data systems to facilitate the collection, display, access, manipulation, and dissemination of information for various NASA efforts. Marshall supported a four-dimensional display program for the Man-computer Interactive Data Access System (McIDAS) developed by the University of Wisconsin, and explored ways to use the system for NASA's Earth Science program. Marshall also helped with another Earth sciences data system, WetNet, a system that integrated data from satellites and ground stations in order to evaluate the global moisture cycle.³

Marshall's involvement in research programs extended back to the pre-NASA days, when the Army Ballistic Missile Agency (ABMA) helped develop and launched Explorer I. Since then, *Skylab's* Apollo Telescope Mount, HEAO, and the diverse payloads flown aboard Spacelab gave testimony to the Center's pathbreaking work in various emerging fields of space science.

Marshall scientists were among the principal investigators for microgravity experiments aboard Spacelab, and the Center's scientists also conducted ground-based microgravity experiments using Marshall's 105-meter Drop Tube/Drop Tower and NASA's KC-135 aircraft. They developed crystal growth experiments designed to produce new materials for technology applications and protein crystals to facilitate the development of new drugs. Other experiments investigated the effect of space processing techniques on materials in microgravity, including undercooling (cooling to below the normal temperature for solidification) and the rate of cooling, and separation techniques for proteins and other biological materials.⁴ The microgravity experiments promoted progress in biology, medicine, and technology.

Marshall began managing, developing, and conducting research in the fields of astronomy and astrophysics since *Skylab* flew in the early 1970s. Development of AXAF had opened new possibilities for broader involvement, but Marshall had long been at work in infrared astronomy, relativity, and cosmic-ray research. In addition to devising experiments, Marshall worked at developing new x-ray and infrared detectors.⁵

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Solar physics research at Marshall centered on examining the solar magnetic field, including studies of the properties of the field, the energy stored there, and the means by which that energy was released. Research included investigations of the solar corona, with the intent of learning more about solar flares, about the solar wind (the expansion of gasses in the corona), and about why the corona is 500 times hotter than the surface of the Sun.⁶

Magnetospheric physics investigated the volume of space influenced by Earth's magnetic field and studied how that field is influenced by the Sun. Scientists at Marshall examined the influence of the solar events and the solar wind on the magnetosphere and how they dispersed plasma outward into space. They concentrated on the "observation of low-energy or core plasma which originates in the ionosphere and has been found to supply plasma for the entire magnetosphere." They developed experiments, hardware, and software to measure plasma flow and evaluated data from previous Shuttle and satellite missions.⁷

Aeronomy examines the interaction between gasses in Earth's upper atmosphere and the Sun's electromagnetic and corpuscular radiation. By gathering data from instruments carried by balloons, on satellites, and on the Shuttle, Marshall scientists were able to learn more about the nature of Earth's atmosphere by studying photochemical and dynamical processes in the ultraviolet and infrared regions of the spectrum.⁸

One of the applied research programs at Marshall was the Center's portion of NASA's Mission to Planet Earth. The Marshall Earth Science and Applications program applied space technology to study Earth's atmosphere, land surface, and oceans. Activities included the invention of theoretical models, creation of remote sensing instruments, analysis data gathered from satellite and Shuttle flights, design of simulations, and experimentation on Earth, in the near-Earth atmosphere, and from spacecraft. Marshall's Global Hydrology and Climate Center, for example, developed sensors in support of the Earth Observing System; one of these instruments, the lightning imaging sensor, examined the global distribution of lightning. Other Earth sciences investigations involved studies of temperature variations, observations of soil and snow properties, atmospheric modeling, studies of Earth's hydrological cycle, and climate dynamics. The many direct applications of Earth science projects included predictions of weather and violent storms, and the availability of data for decisions regarding water use.⁹

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If Marshall's research capability demonstrated ways in which the Center added breadth, its technology programs showed how the Center increased depth in areas of traditional strength. Marshall originated as a propulsion team, and at the beginning of the fourth decade the Center remained in the vanguard of propulsion engineering. In the late 1980s, in the aftermath of the *Challenger* accident, Marshall's Propulsion Laboratory contributed to redesign of the Shuttle solid rocket motor, but also worked on improvements in the Shuttle main engine.

The solid rocket motor redesign effort at Marshall was a high profile activity, and the Propulsion Lab contributed in many ways to returning the Shuttle to flight. The lab built a tool to measure roundness of the solid rocket motor case, and Morton-Thiokol immediately put it to use. Engineers helped develop a new material to use as a sealant to replace that previously used in the O-rings. They applied computational methods to the internal flow analysis of the booster to detect possible localized burning pockets. The Propulsion Lab was involved at every step of redesign.

Marshall's Science and Engineering laboratories also worked on improvements to the Shuttle main engine. The Materials Laboratory sought a solution for the problem of the cracking of turbine blades that continued to plague the main engine, and the Dynamics Laboratory developed a computational fluid dynamics model to study the problem. Fuel flow within the engine was always a complex problem. Engineers devised a meter to measure fuel flow in the engine, began developing a diagnostic system to measure flow at the nozzle exit, and devised means to simulate the inherently instability caused by relative motion between rotor and stator airfoils.¹⁰

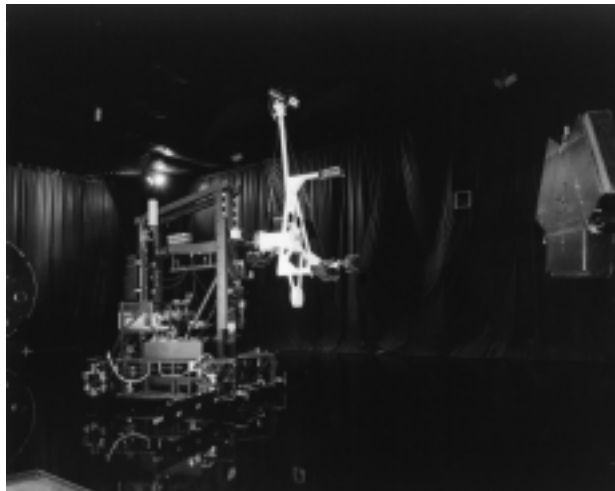
Advanced welding techniques were among the activities pursued in Marshall's Materials and Processes Laboratory. The variable polarity plasma arc welding system was one of the significant advances in welding technology to come out of Marshall's labs, and in the late 1980s the lab developed a mathematical model to evaluate and improve the system. X-rays of welds on the Shuttle's external tank occasionally showed fine lines, and after years of investigation the lab duplicated the lines and identified their cause. Another project related to the external tank was the invention of an improved foam insulation coating. To complement the Propulsion Lab's work on turbine blade fracture, the Materials and Processes Laboratory devised a new computer code for fracture mechanics

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analysis. When the Shuttle main engine's high-pressure oxidizer turbopump end bearing failed to meet its design life requirements, the lab devised a bearing tester to evaluate bearing performance.¹¹

The Structures and Dynamics Laboratory included facilities for testing, analyzing, and improving the dynamics and structural integrity of systems developed at Marshall. The lab evaluated the effect of such variables as load weight and distribution, temperature, vibration, fluid dynamics, strength, and durability on systems components developed at the Center. Structures and Dynamics activities ranged from designing structures and assembly techniques to developing pointing control systems, life support systems, and thermal protection systems. Its work in thermal protection systems, for example, led the lab's Productivity Enhancement Facility to create a simulation system to improve the application of spray-on foam insulation to the Shuttle external tank. The Space Station program drew on the lab's expertise to study means by which the station could contend with the threat posed by space debris and micrometeoroids.¹²

Robotics was central to the development of new NASA systems. Marshall contributed by pioneering robotic methods of docking and remote servicing of orbital platforms. The Center's Orbital Hardware Simulator Facility gave testimony to the latest generation of sophisticated robotic technology. The facility's Dynamic Overhead Target Simulator (DOTS) operated



Docking simulation in Marshall's Teleoperation and Robotics Research Facility.

in eight degrees of freedom, and could position a 1,000-pound load to within an accuracy of one-quarter inch. Operating in conjunction with the Air Bearing Mobility Unit, DOTS could support a variety of docking and stationkeeping operations.¹³

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Marshall's Space Systems Lab performed a wide variety of tasks. Its engineers provided support for Space Station, AXAF, and Spacelab. In support of Space Station, they developed the system for the distribution of power in habitation and laboratory modules, a complex system that required the invention of computerized processors and artificial intelligence systems. They also help develop technology for the development and integration of experiments and instruments. They also helped developed methods of welding in space, created a lightweight composite intertank for the advanced launch system, and designed the technology mirror assembly for AXAF.¹⁴



Advanced technology solar array tested in space.

Marshall's Astrionics Laboratory had experts on electrical systems, instrumentation and control, computers and data management, software, optics, avionics simulation, and electrical power. These engineers contributed to the subsystems of virtually all of Marshall's projects. Among the lab's projects was the autonomously managed power system (AMPS), a complex apparatus designed to control spacecraft without commands from the ground. It involved subsystems for fault detection and recovery, load management, status and control, and an expert system for fault monitoring.¹⁵

It took three decades to build an organization of such wide-ranging capabilities. Spinning off from its propulsion specialty, the Center developed diverse skills by contributing to NASA's most ambitious and complex projects of the seventies and eighties. The Center extended its expertise in rocketry by its work on the Space Shuttle, helping produce reusable liquid-fuel engines and solid rocket motors. Marshall oversaw development of the Hubble Space Telescope with its complex interfaces and precise systems of optics and pointing and control. The Center worked with the European Space Agency on Spacelab which

became the embodiment of Marshall's diversification; this experiment module for the Shuttle combined the Center's expertise in spacecraft and scientific instrument engineering, human systems, and research in multifarious scientific and technical disciplines. Marshall also drew on all its skills in its contributions to the Space Station, helping NASA conceive a configuration that could be constructed in space, carried in the Shuttle, capable of sustaining a crew and supporting experiments for decades, and salable to Congress.

Space Shuttle, Hubble Space Telescope, Spacelab, and Space Station projects had common political and technical features which produced more complicated challenges than those Marshall faced during Apollo. The technology and technical interfaces were much more complex after the 1960s. The Shuttle orbiter and propulsion system were designed as one unit while the Saturn boosters and Apollo spacecraft had been designed separately with guidance-and-control as the main interface, and Space Station designs multiplied the complexities of the Shuttle program. Even as Marshall's technical challenges grew, the Center lost the advantages of the Arsenal system and in-house manufacturing capability. Development was in the hands of contractors and measuring their performance became more difficult because Marshall could not build prototypes to use as "yardsticks." Nor could the Center address technical problems by hiring new experts because of personnel policies and austere budgets.

Moreover, Marshall personnel had to adjust to political and financial decisions that imposed severe restraints on their technical work. In the seventies and eighties, mission goals and hardware designs were more subject to external constraints and changes, mainly because Congress exercised greater scrutiny over NASA and was more willing to slash budgets. No longer did NASA have a privileged status as part of the struggle against Communism. For instance, Congress backed and funded Apollo in the sixties, but throughout the eighties kept questioning the Space Station and limiting its budget. After the 1960s, Congress would usually not give NASA the extra money needed to meet the unexpected costs typical in research and development. To cope with the budgetary shortfalls, NASA reduced tests and prototypes, stretched schedules, and restructured the project to cut costs. For example, while NASA had received sufficient funds to meet Apollo's end-of-the-decade deadline, unrealistic budgets caused the Hubble Space Telescope to fall years behind the original schedule.

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In addition in the seventies and eighties, Marshall's organizational environment became more complicated than the sixties. The Center worked with other NASA Centers, multitudinous contractors and universities, other federal agencies (especially the Department of Defense), and foreign space agencies. Coordinating these complex coalitions was often difficult because each entity wanted to maintain independence, hide problems, or impose ideas on the others. Work with multinational partners introduced diplomacy as another factor in NASA decisions.

In a different way, NASA's travails with the Space Station in the eighties revealed the complex and uncertain environment in which Marshall worked. When Congress cut funding and forced redesign, international partners felt the effect. Redesigns, reorganizations, and annual congressional votes on whether to continue work and how much money to appropriate stretched schedules and forced Marshall to be flexible and resourceful.

Marshall's journeys to the heavens were further complicated by disasters and false starts in the 1980s. The *Challenger* accident and the Hubble mirror flaw demonstrated how rigorous procedures could not eliminate human error from a complex technical endeavor. Prior to each event, Marshall and its contractors had struggled with difficult questions about how to balance spending between hardware development and ground tests, devise realistic tests, interpret technical data, report complicated engineering evaluations, and extend communications. After each event, Marshall strove to learn engineering and management lessons and thus to avoid repeating the problems. The Center improved quality practices and communications and emerged stronger than it had been before.

Marshall overcame most of the challenges and constraints of the 1980s; its projects led to significant advances in space exploration and science. The Center redesigned the Shuttle propulsion system, and soon the Space Shuttle and Spacelab were again providing regular access to Earth orbit. After NASA corrected the flaws in Hubble's optics, taking advantage of how Marshall had designed the satellite for repair in space, the space telescope gave new insights into the far reaches of the universe.

Marshall and NASA in 1990 were passing through an era as uncertain as the late 1950s or the early 1970s. While using the past to predict the future is risky, the previous periods of uncertainty do provide some harbingers of events to

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come. In the past the engineers and scientists in Marshall's laboratories had proposed ideas for new missions, launch vehicles, experiments, and spacecraft, thus inventing new ways for NASA to fulfill its mission of space exploration. As a result of diversification, the Center in



Aerial view of MSFC looking south in 1992.

1990 had great expertise and was ready to undertake grand endeavors. And as in earlier eras of uncertainty, decisions on the use of this resource rested outside the Center.

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- 1 C.R. Darwin, "Advanced Studies," in Research and Technology 1988: Annual Report of the Marshall Space Flight Center (NASA TM-100343), p. 1.
 - 2 Research and Technology 1985 (NASA TM-86532), pp. 9-24; Research and Technology 1988, pp. 19-42.
 - 3 Research and Technology 1989: Annual Report of the Marshall Space Flight Center (NASA TM-100369), pp. 43-57.
 - 4 Research and Technology 1988, pp. 48-58; Research and Technology 1989, pp. 60-76.
 - 5 Research and Technology 1989, pp. 77-81.
 - 6 Research and Technology 1989, pp. 82-95.
 - 7 Research and Technology 1989, p. 96.
 - 8 Research and Technology 1989, pp. 107-110.
 - 9 Research and Technology 1989, pp. 111-165.
 - 10 Research and Technology 1988, pp. 124-158; Research and Technology 1989, pp. 168-207.
 - 11 Research and Technology 1989, pp. 208-227; Research and Technology 1988, pp. 159-72.
 - 12 Research and Technology 1989, pp. 228-234.
 - 13 Research and Technology 1989, p. 180.
 - 14 Research and Technology 1989, pp. 243-259.
 - 15 Research and Technology 1989, pp. 261-62.